MISSION ANALYSIS AND FLIGHT MECHANICS OF EARTH EXPERIMENTAL MISSIONS

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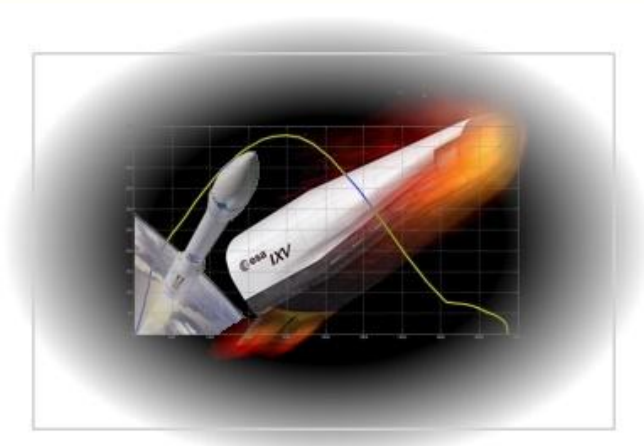

Speaker:
Rodrigo Haya
DEIMOS Space

Agenda

- **Motivation and Objective**
- **Earth Experimental Missions**
- **The RADFLIGHT demonstrator**
- **The BLAST demonstrator**
- **The IXV demonstrator**
- **Conclusions**

Motivation and Objective

- **Project Motivations**
  - In the European context, several experimental missions have been planned to improve the knowledge of hypersonic systems. The general aim is to increase the safety of the future re-entry or planetary probe missions and optimize designs by reducing margins
  - From a planetary probe perspective, those Earth missions are enablers of EDL technologies needed for future missions
  - The Mission analysis and Flight Mechanics of an experimental mission plays a key role to assess the feasibility of the mission and to advance the expected benefits before entering in detailed definition phases.
  - DEIMOS Space is responsible for the Mission Analysis, Flight Mechanics and GNC for several of those experimental vehicles
- **Presentation Objectives**
  - Present the Mission Analysis and Flight Mechanics of the RADFLIGHT, BLAST and IXV mission

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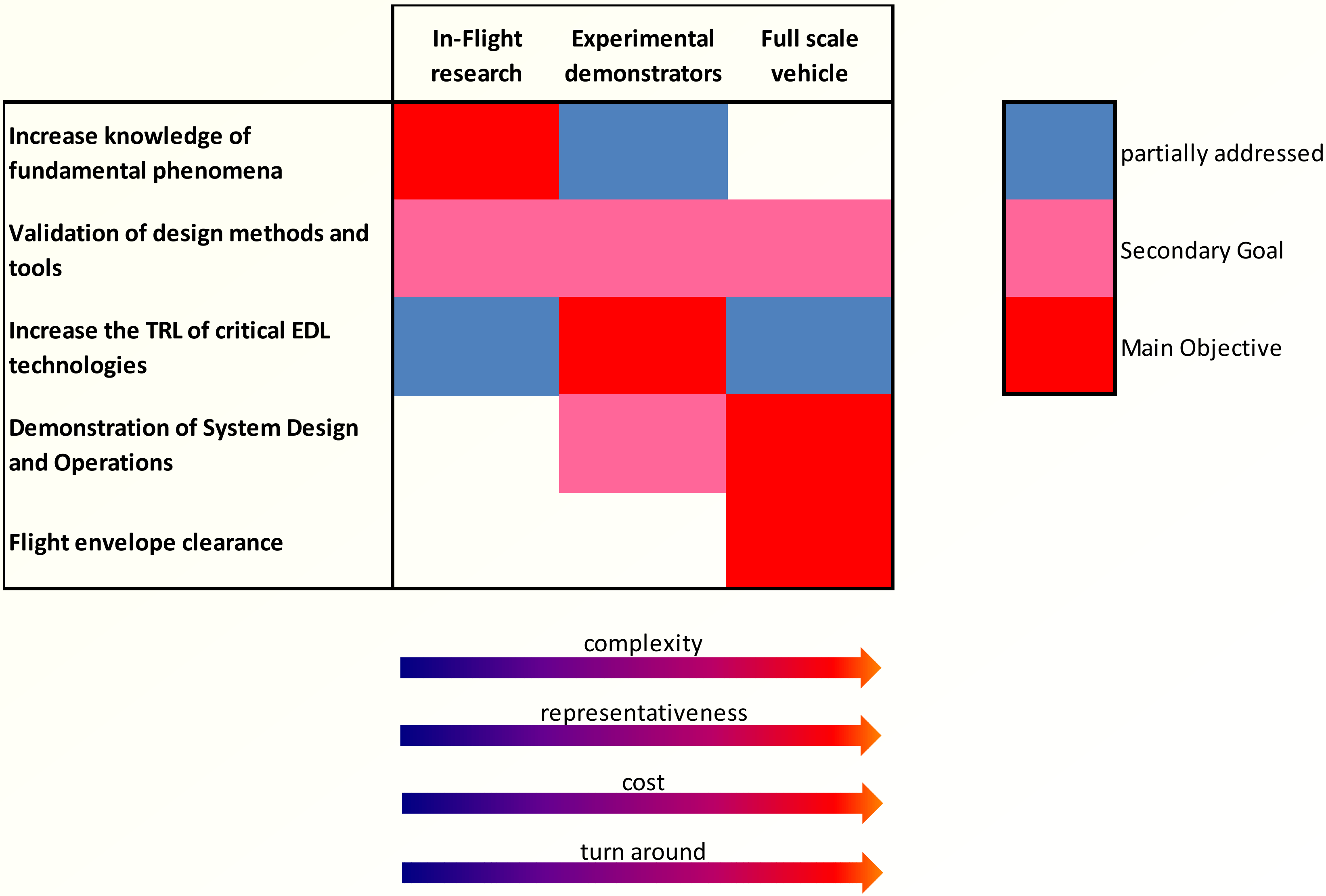
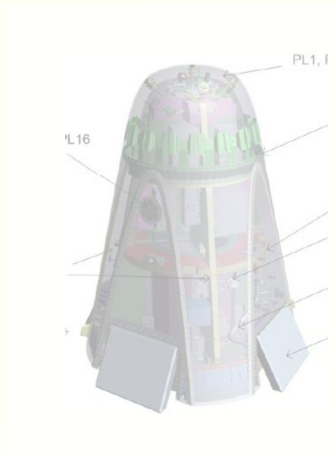
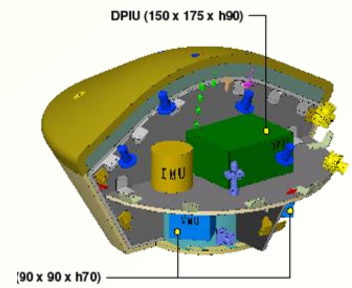
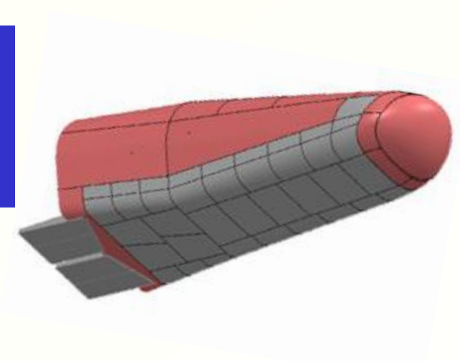
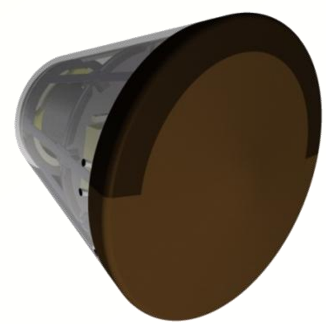
Experimentation Objectives



Experimental Missions Overview

	LEO Speed		High Speed	
In Flight Research		**EXPERT** 5 km/s 1.6 L 450 kg Ballistic pre-launch (2011 launch)		**RADFLIGHT** 11 km/s 0.7 m ϕ 40 kg Ballistic Phase A
Experimental demonstrators		**IXV** 7.5 km/s 5 m L 1.9 Ton Full GNC CDR passed (2014 launch)		**BLAST** 10.9 km/s 1.5 m ϕ 460 kg Full GNC Phase A

Credits:TASI

RADFLIGHT: Mission Overview

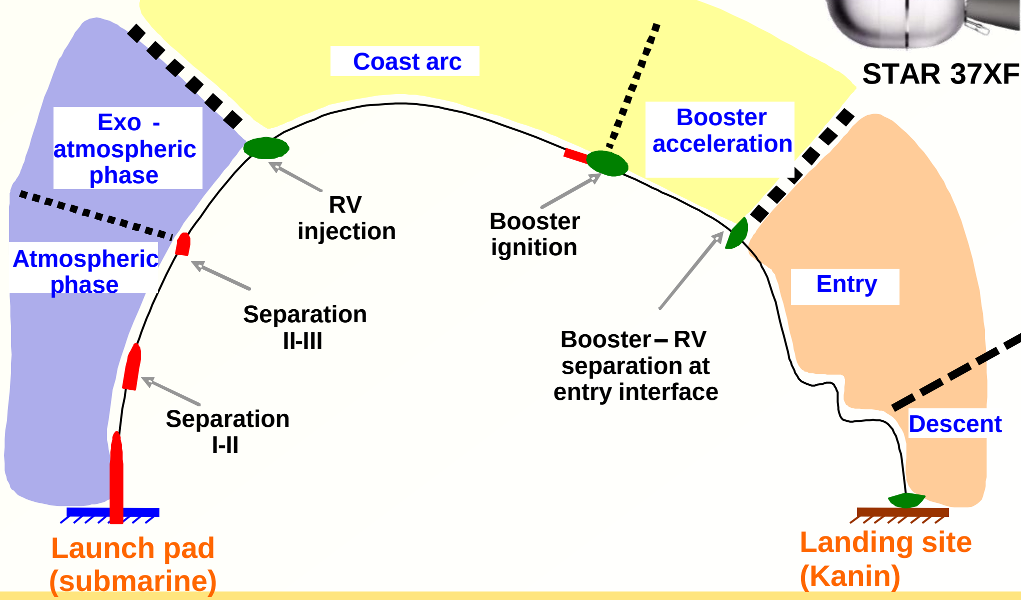
Main mission objectives are:

- Improve the limited knowledge on radiation process, radiation/ablation coupling and transition to turbulence
- Reduction of the large margins in TPS sizing for high speed re-entry
  - Validation of physical modeling within numerical tools
  - Use of plasma wind tunnel for flight extrapolation and scaling

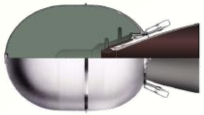
Mission Elements

Launcher

VOLNA



Kick-Stage (Solid, spin)



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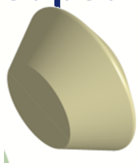
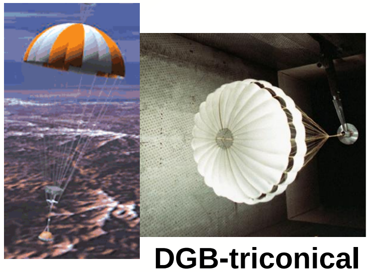
Re-entry Capsule



Stardust like



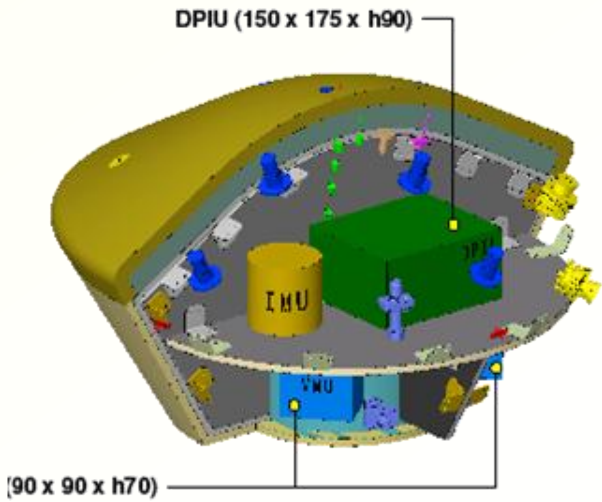
DGB-triconical parachute sequence

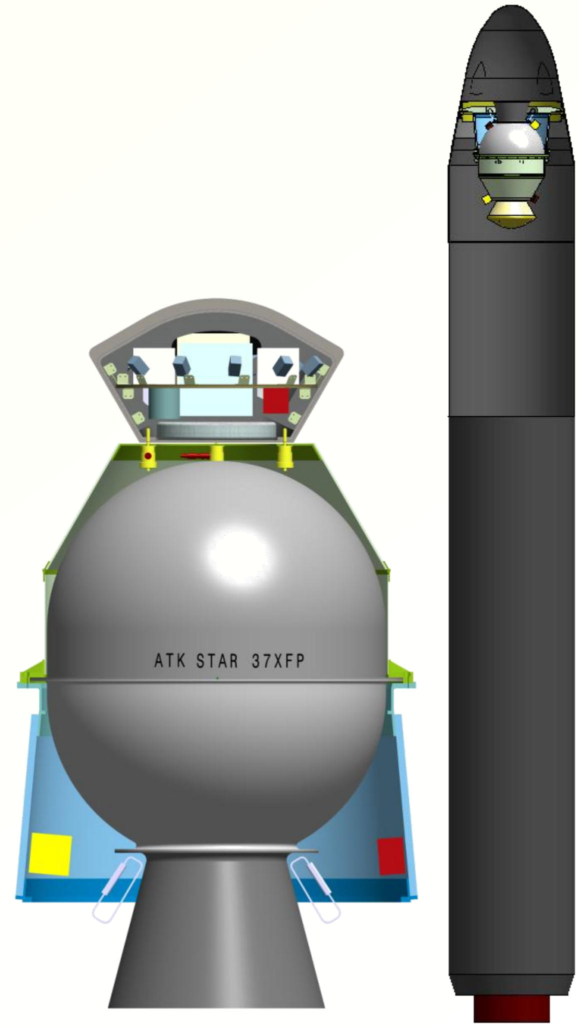
RADFLIGHT: System overview

System Highlights

- Highly constrained layout
- PICA like TPS
- 38 kN class booster element
- Need for miniaturised avionics
- Recoverable capsule (no TM)

o/b instruments
Spectometer
Radiometer
Isotherm detector
Heat Flux / Pyrolisis plugs (HFP)
Thermocouples (TC)
Pressure ports
Flux /pressure probe (CFP)
IMU

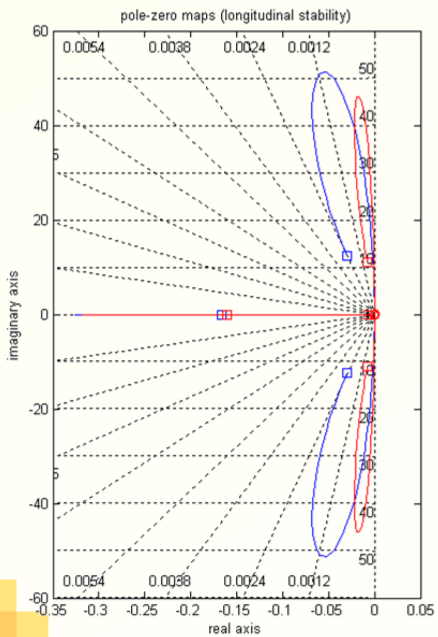


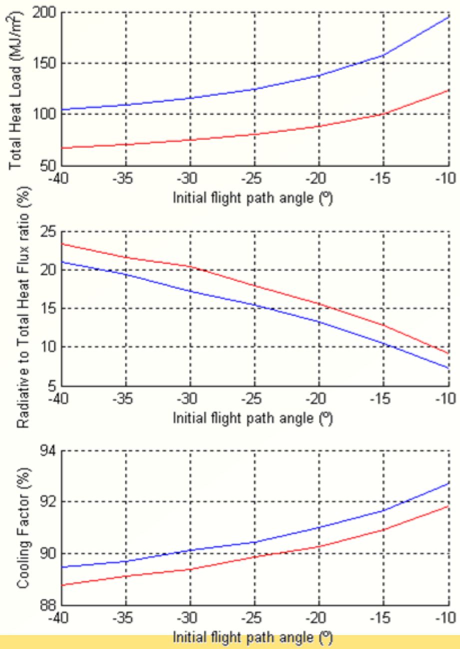


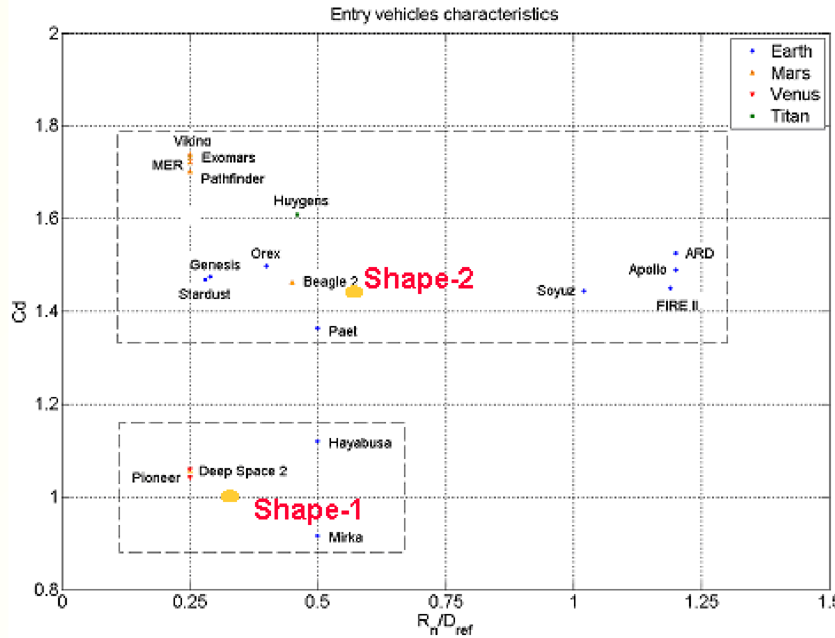
Credits:TASI

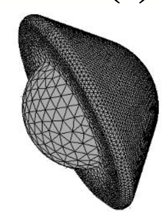
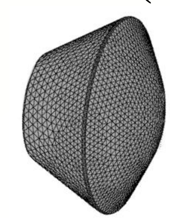
RADFLIGHT: Flight Mechanics

- **Two vehicles analyzed**
  - Static & Dynamic Stability
  - Entry Performances
  - Packaging
- **Stardust like shape selected**



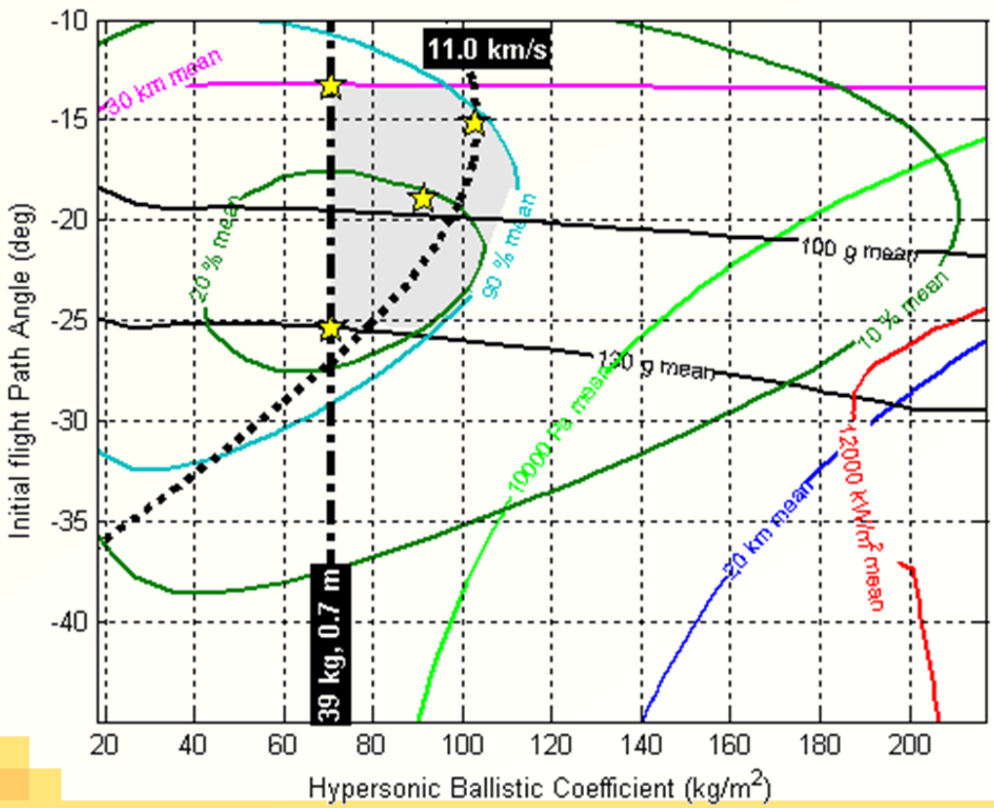




	MSR (1)	Stardust (2)
Shape		
Half cone angle (º)	45	60
Nose radius (m)	0.23	0.40
Diameter (m)	0.7	0.7
Reference chord (m)	0.437	0.430
Reference drag coefficient	0.9964	1.4341

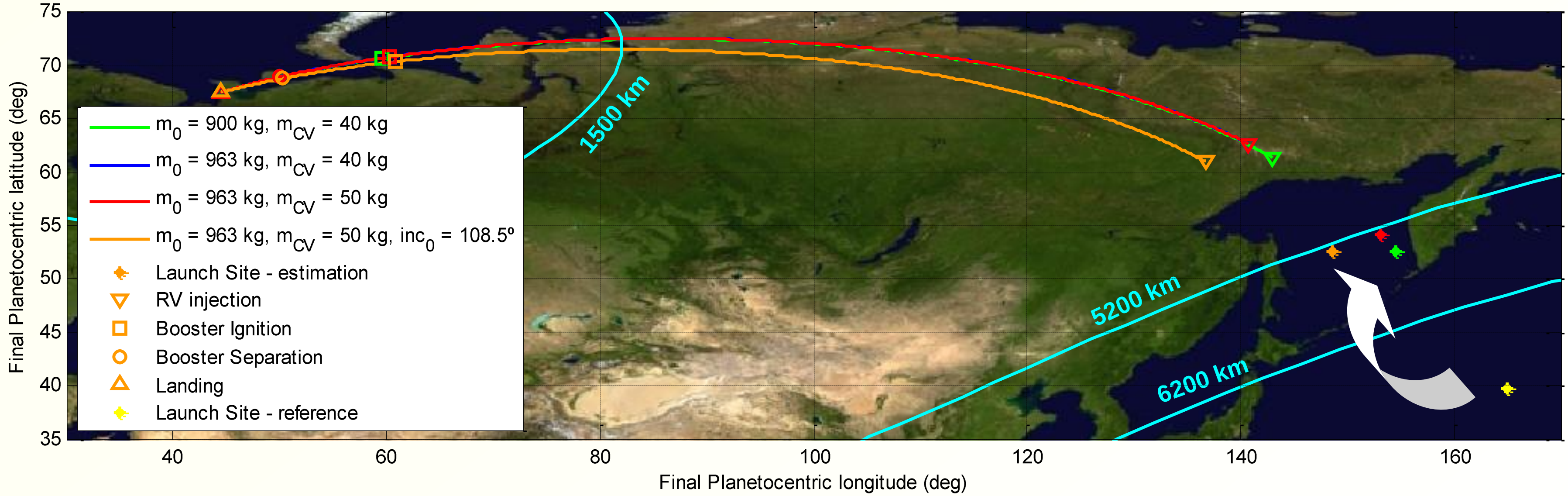
RADFLIGHT: Entry Corridor

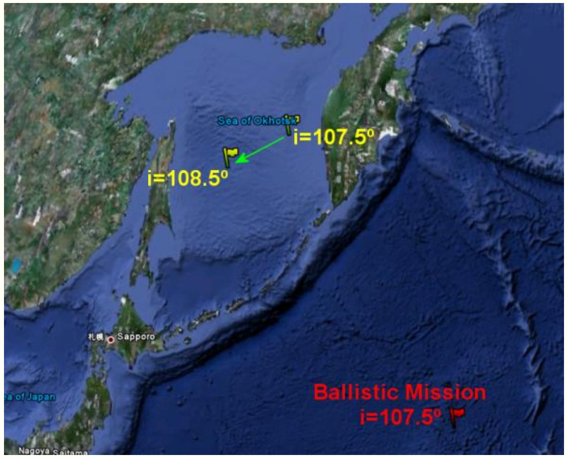
- **Coupled analysis from launch to parachute deployment**
  - Radiative + convective heat fluxes
  - Minimum level of radiation
  - Minimum level of convective – radiative coupling
- **Sizing and reference trajectories selected**

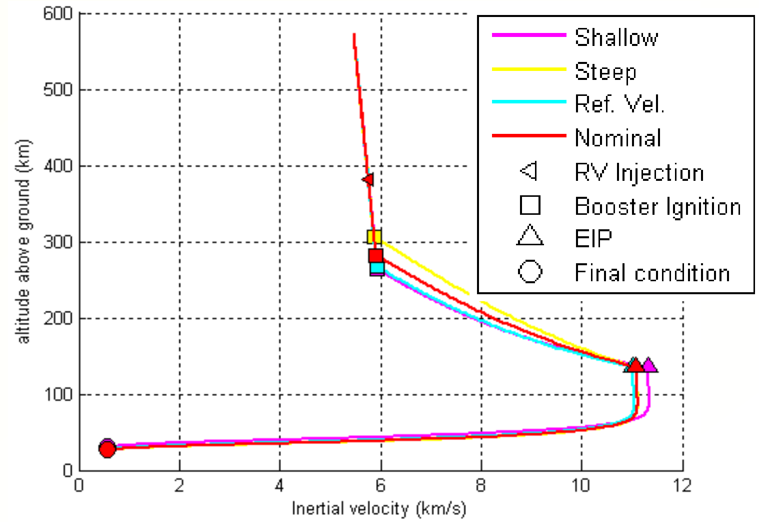


Case	Value		
RV INJECTION			
Injected mass (s)	900	963	963
Inclination (deg)	107.51	107.48	108.5
BOOSTER INGITION			
Time from launch (s)	1073.23	1035.73	1035.6
Altitude (km)	262.16	269.49	269.42
Co-rotating velocity (m/s)	5932.27	5853.05	5860.44
EIP (100 km)			
Time from launch (s)	1136.65	1103.31	1103.19
Co-rotating velocity (m/s)	11064.55	11008.2	11015.44
Co-rotating fpa (deg)	-18.34	-18.21	-18.20
Mass (kg)	39.92	49.92	49.91
Max. Convective Heat Flux (MW/m^2)	8.19	8.98	8.99
Max. Radiative Heat Flux (MW/m^2)	1.61	1.92	1.94
Max. Total Heat Flux (MW/m^2)	**9.4**	**10.35**	**10.38**
Final Total Heat Load (MJ/m^2)	**99.46**	**111.48**	**111.77**
Min. Coupling factor (%)	**89.37**	**89.26**	**89.21**
Max. Total Load factor (g)	**93.47**	**93.53**	**93.55**
FINAL CONDITION			
Time from launch (s)	1177.61	1144.98	1144.88
Downrange from Launch (km)	**5453.78**	**5260.22**	**5266.58**

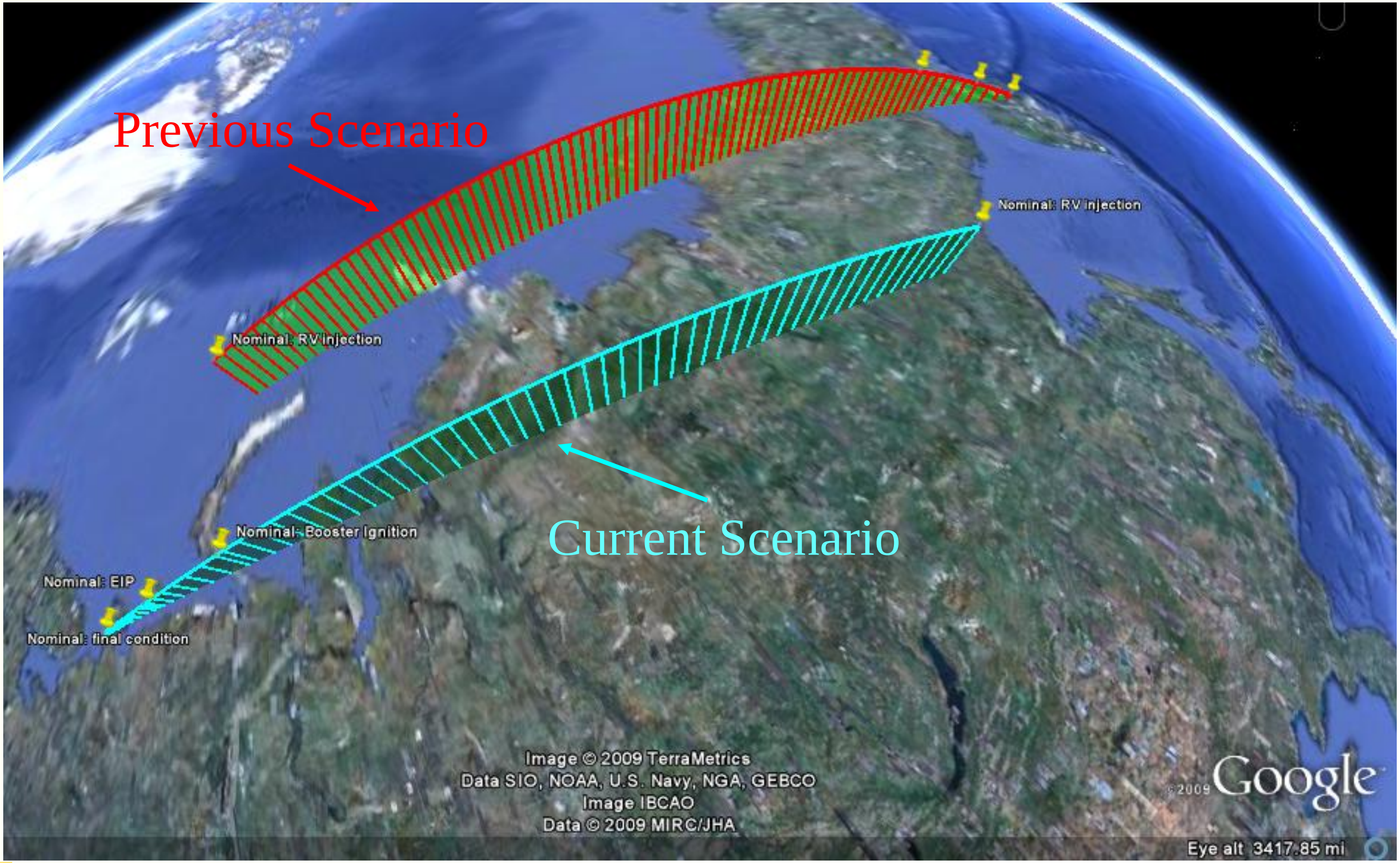
RADFLIGHT: Trajectories







RADFLIGHT: Trajectories



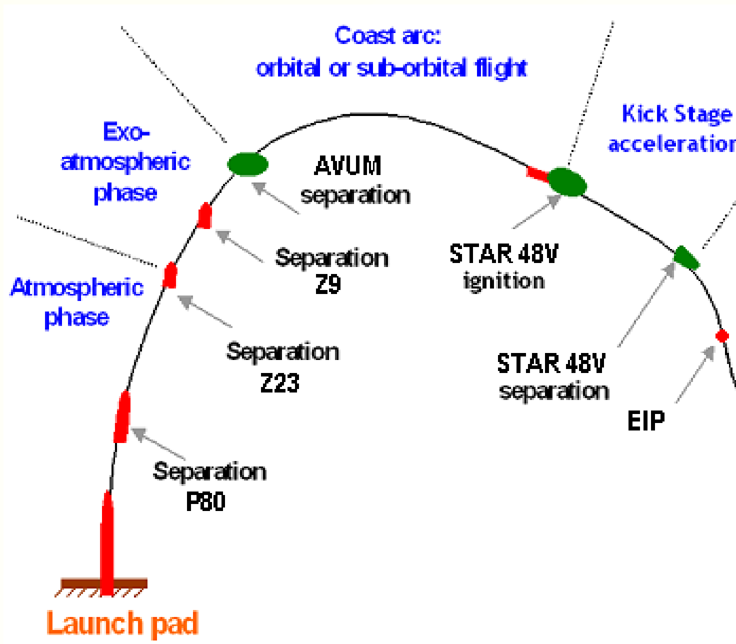
BLAST: Mission Overview

- Main mission objectives are:
  - Testing system level capabilities
  - Assessing a set of enabling technologies
    - GNC in skip entry mode
    - Entry, Descent & Landing
    - High-Energy TPS solutions
  - Collecting environmental data through on-board experiments
    - flowfield at super-orbital & suborbital speed
    - validation of predictive tools

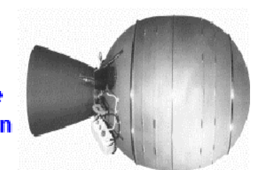
Launcher

VEGA
Lift-off Mass ~140 t

(Back-up: DNEPR)



Kick-Stage (Solid, TVC)



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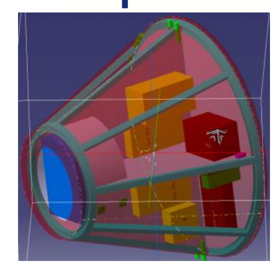
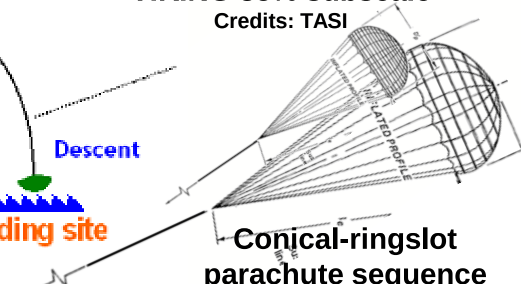
Earth Re-entry Capsule



VIKING 35% subscale
Credits: TASI



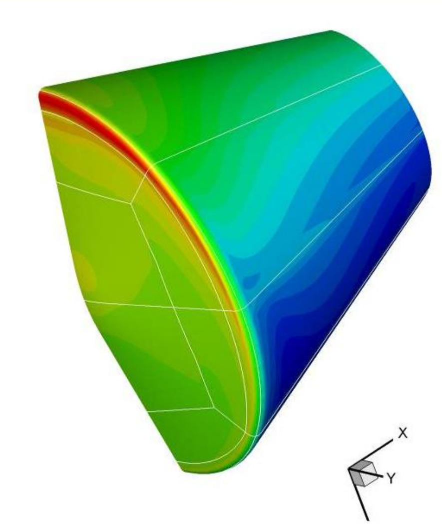
Conical-ringslot parachute sequence

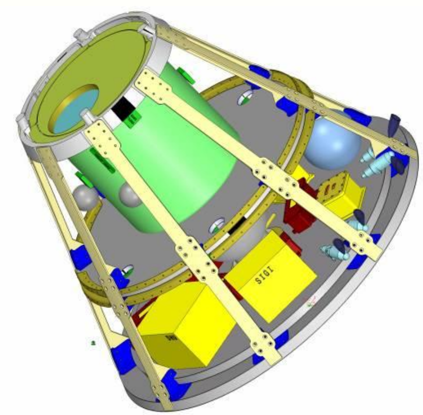
BLAST: System overview

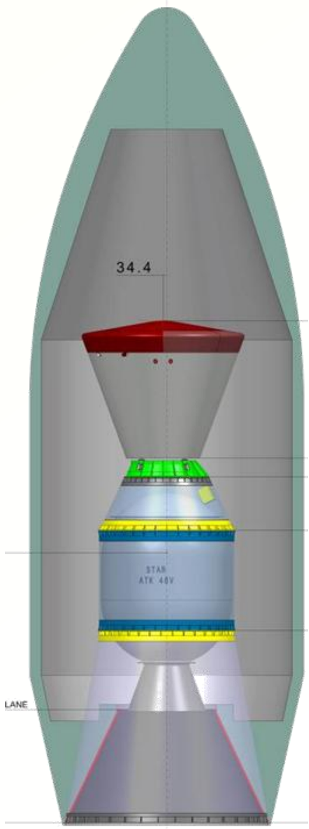
System Highlights

- Adaptaion to Vega becomes a driving requirement
- From Biconic to Viking like shape
- PICA like TPS
- 78 kN class booster element
- Recoverable capsule
- Telemetry & o/b storage

o/b instruments
Spectometer
Radiometer
Isotherm detector
Heat Flux / Pyrolisis plugs (HFP)
Thermocouples (TC)
Pressure ports
Flux /pressure probe (CFP)
Magnetometer
IMU
GPS







Credits:TASI

BLAST: Flight Mechanics

ERC: vehicle configuration and entry corridor (CoG, Trim, Spin, FPA)

Extended analysis to obtain flight properties required to successfully perform the mission

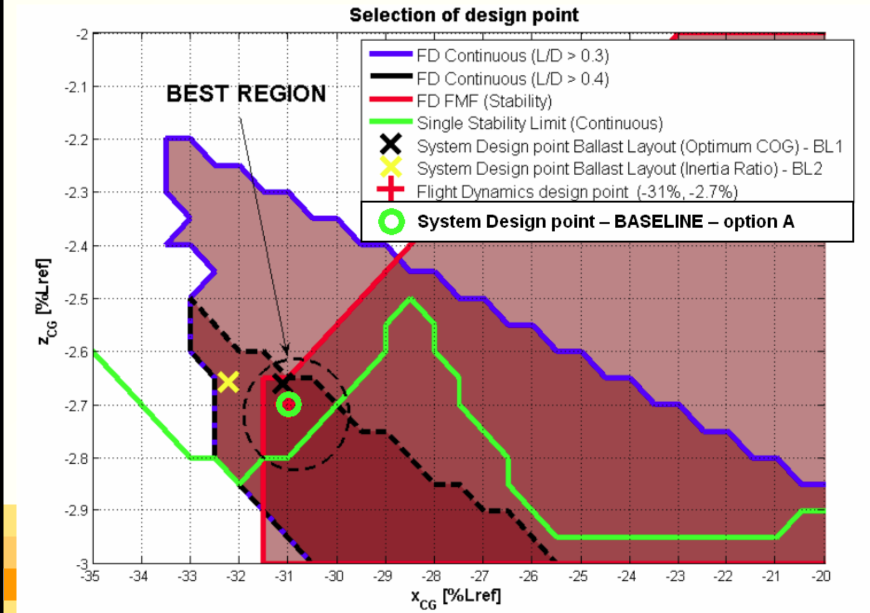
Trim, monostability, FQ and path constraints in Continuous and FMF

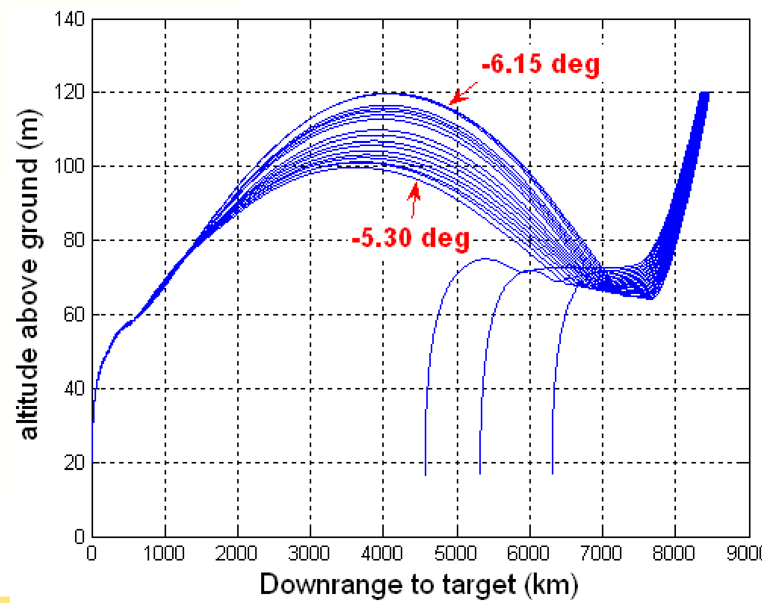
Capsule CoG Location and AOA Trim

System Design		
Property	Unit	Value
Xcog	mm (% Lref)	477.4 (31%)
Ycog	mm (% Lref)	0.44 (0.03%)
Zcog	mm (% Lref)	-41.5 (-2.7%)
Ixx	kg/m2	85.5
Iyy	kg/m2	94.5
Izz	kg/m2	91
Ixy	kg/m2	0.2
Ixz	kg/m2	-2.1
Iyz	kg/m2	0.1
Dyn. Unb.	deg	18.5

Common FPA Entry Corridor in ballistic and skip entry modes

FPA at EIP (-5.8º), vehicle inertia properties (dynamic unbalance) and spin rate (3RPM) in ballistic

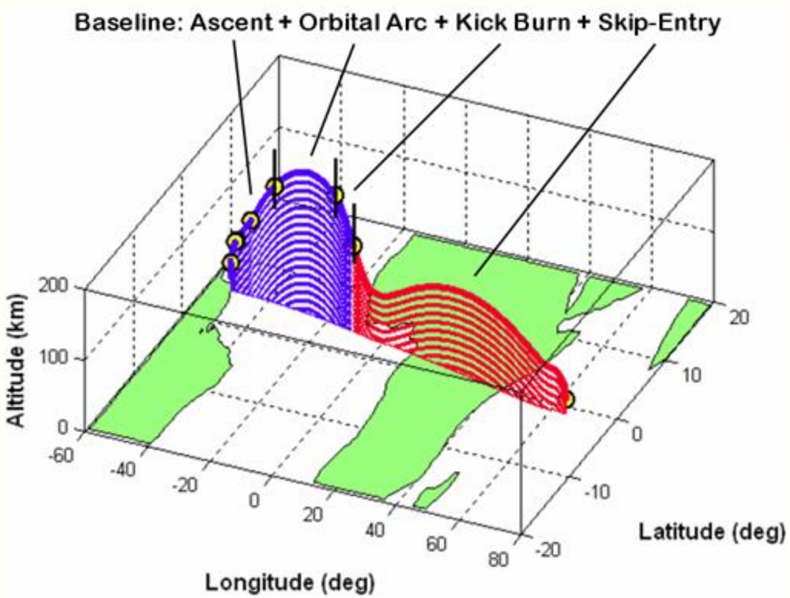


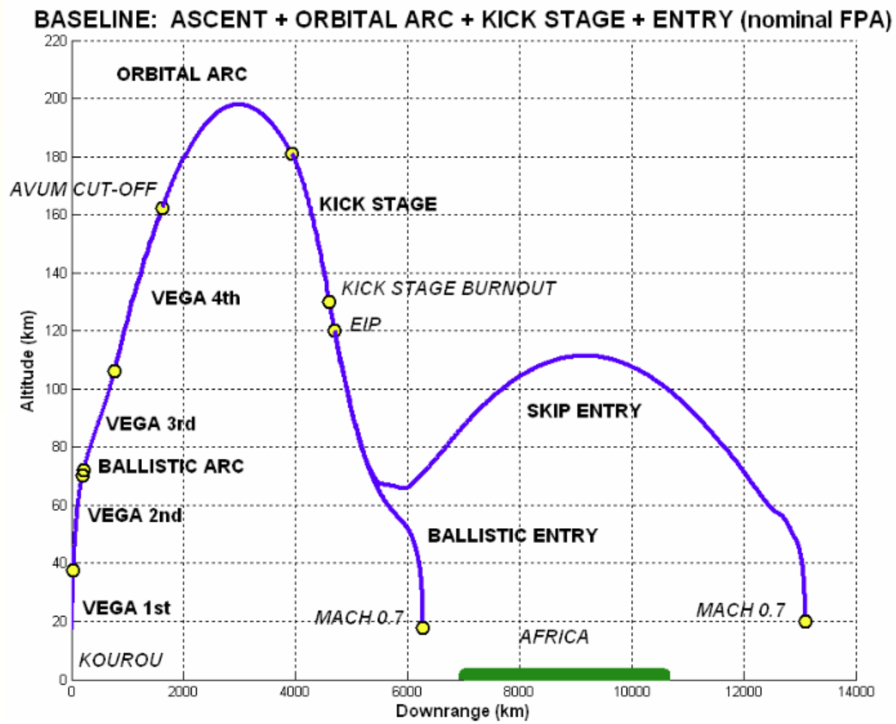


BLAST: mission profile

End to end (launch to DRS) multi-phases optimization problem

- Objective: Achieve lunar entry conditions at EIP with VEGA + kick stage
- ERC CoG and Trim AOA from configuration analyses
- Optimum orbit at end of VEGA: 200 x -900 km
- FPA at EIP from entry corridors (skip + ballistic) = -5.8º, Vi = 10.9 km/s
- Compatible with water landing (skip & ballistic) and safe debris



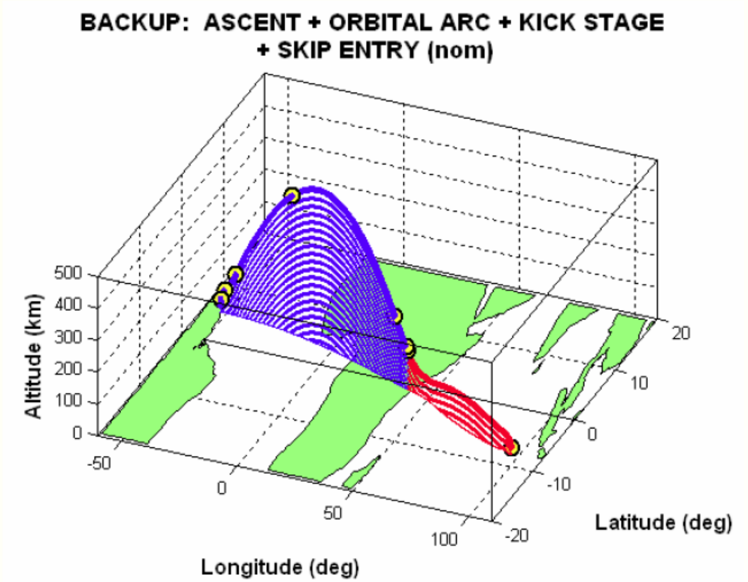


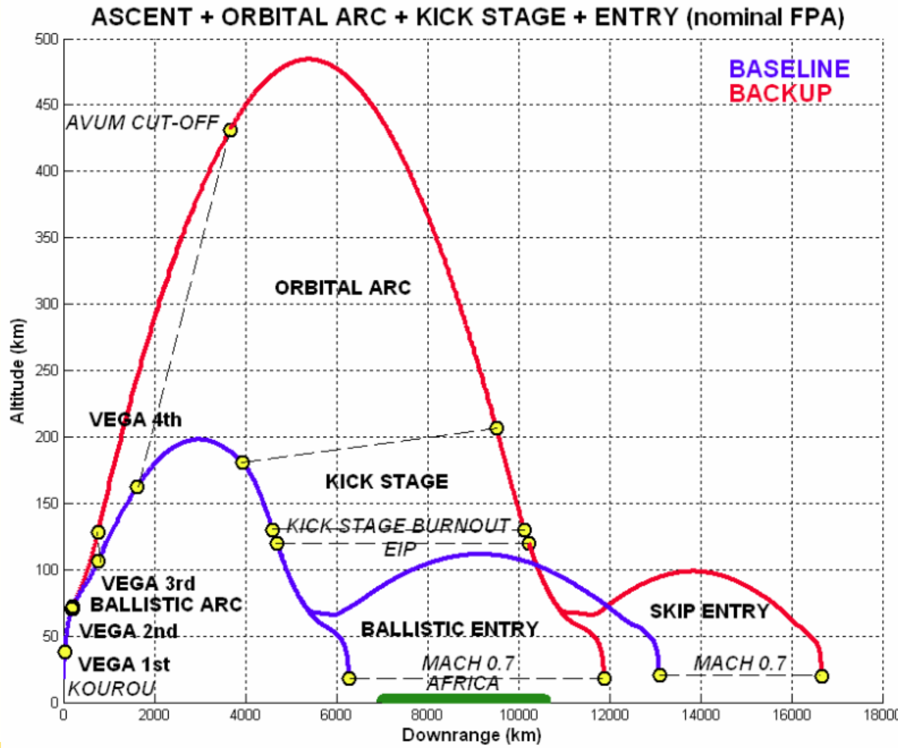
- AVUM partial loading allows 450 kg of mass margins (injected mass: 2742 kg)

BLAST: mission profile (backup)

End to end (launch to DRS) multi-phases optimization problem

- Same Objective as Baseline
- Optimum orbit at end of VEGA: 500 x -900 km
- High Performance in terms of EIP velocity, more stressful on TPS and GNC
- High Safety (stage and debris fallout): water landing in the Indian Ocean
- No mass margin! ⇒ reduction of performances feasible keeping objectives

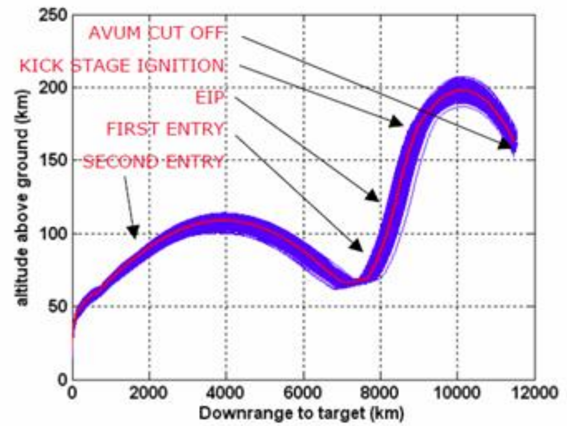




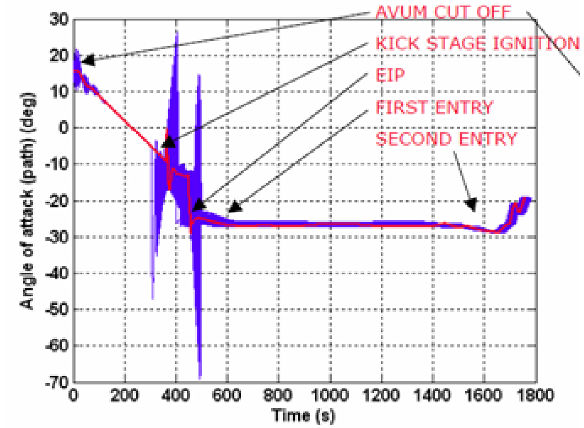
- Both AVUM and kick-stage partial loading (injected mass: 2616 kg)

BLAST: GNC Results

Altitude Profile VS Downrange to Target, significant dispersion at AVUM Cut-Off are taking into account



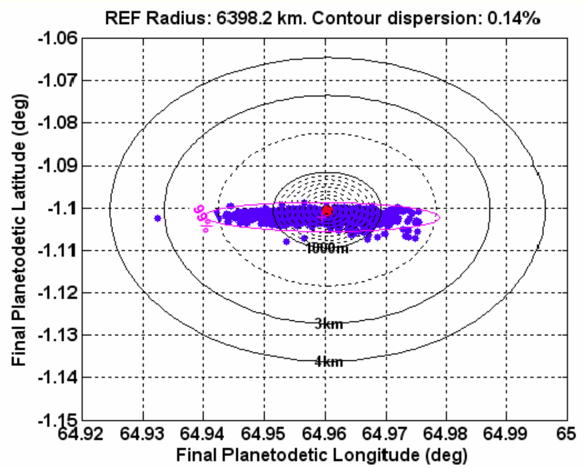
Trim stability is confirmed by AoA dispersion during endo-atmospheric flight at about ±1 deg



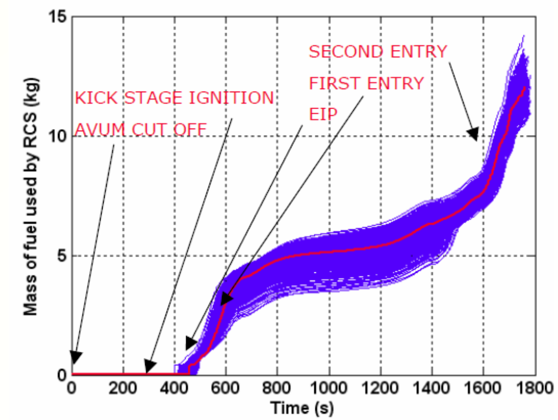
FULL GNC simulation from Launcher separation to DRS deployment:

- **Guided acceleration phase**
- **TVC**
- **Skip entry guidance during entry**
- **1000 shots 6DOF MC campaign**

Variability at EIP:
-5.80º < FPA < -5.65º
10.81 < Inertial V < 10.95 km/s



The implemented guidance and control behaves well resulting in reduced dispersions at the main mission events



Dispersion at Drogue Deployment within 2km

Accuracy is adequate to obtain a max dispersion of 15km at Splashdown with winds

Negligible Fuel Consumption in Exo-Atmospheric Flight

Fuel consumed for Bank Angle modulation during Endo-Atmospheric Flight

IXV: Mission Overview

Main mission objectives are:

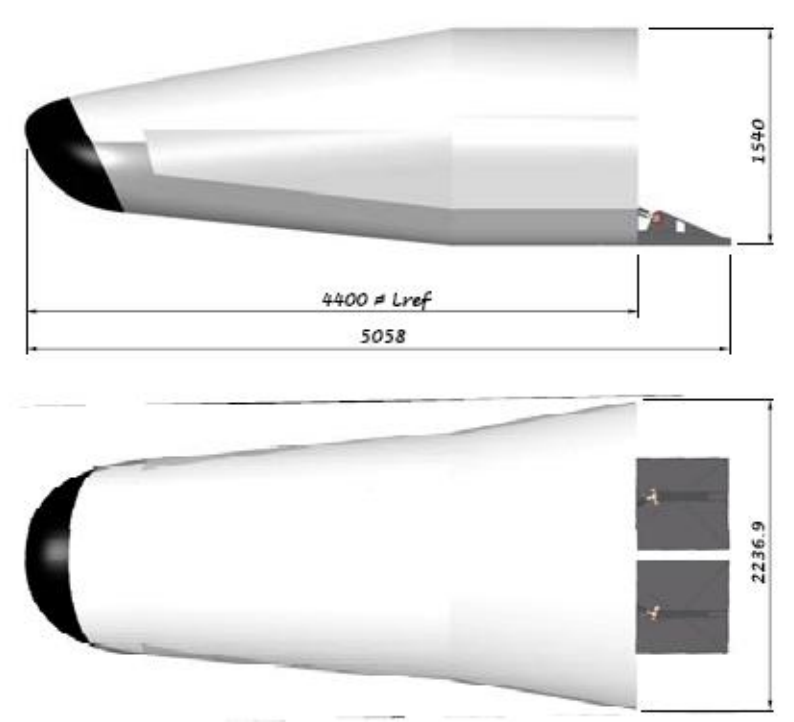
- Integrated System Demonstration
- Technology Experimentation (TPS, GNC, …)
- Technology Validation (ATD, TPS, HS, GNC, …)

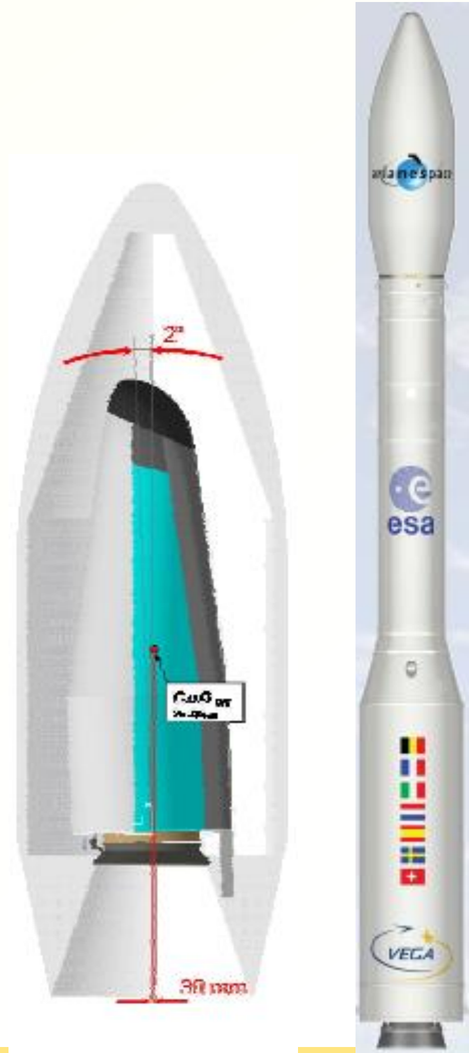
IXV: System overview

System Highlights

- Combination of C/SiC and ablative material
- Recoverable vehicle
- Telemetry & o/b storage
- Active flaps & RCS

o/b instruments
Thermocouples (TC)
Pressure ports
Strain gage
Displacement sensor
Infra red camera
3-axis accelerometer
IMU
GPS

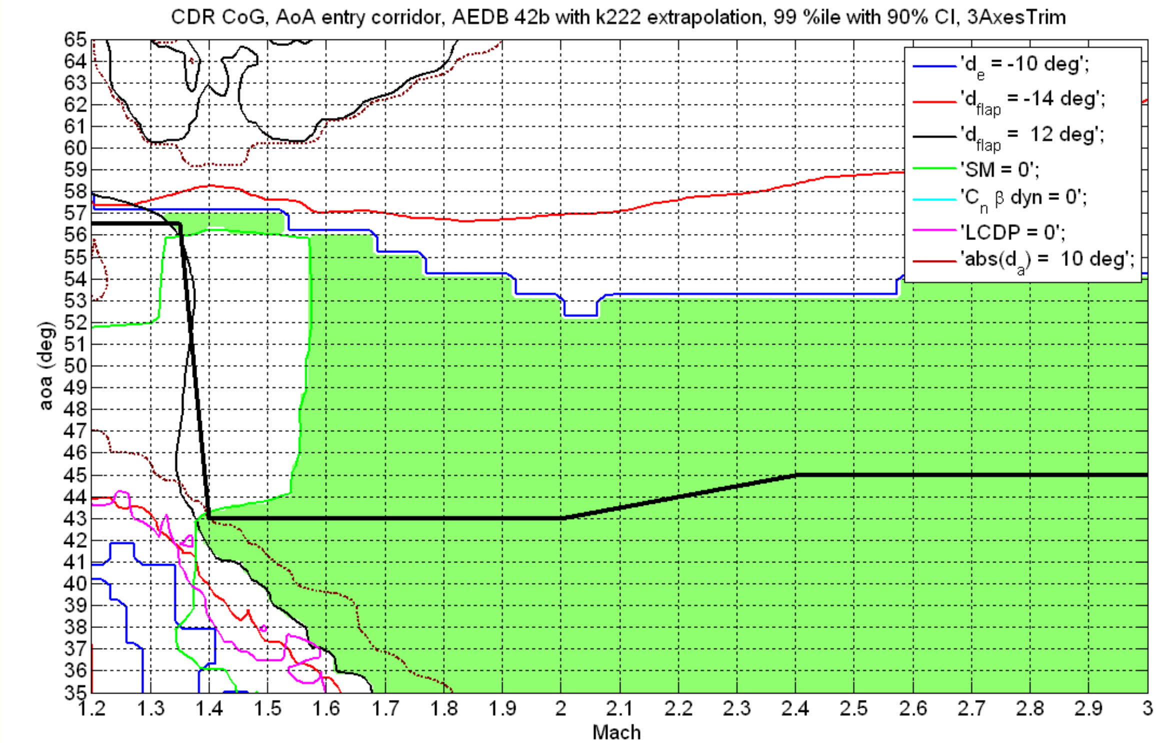




Vehicle Configuration

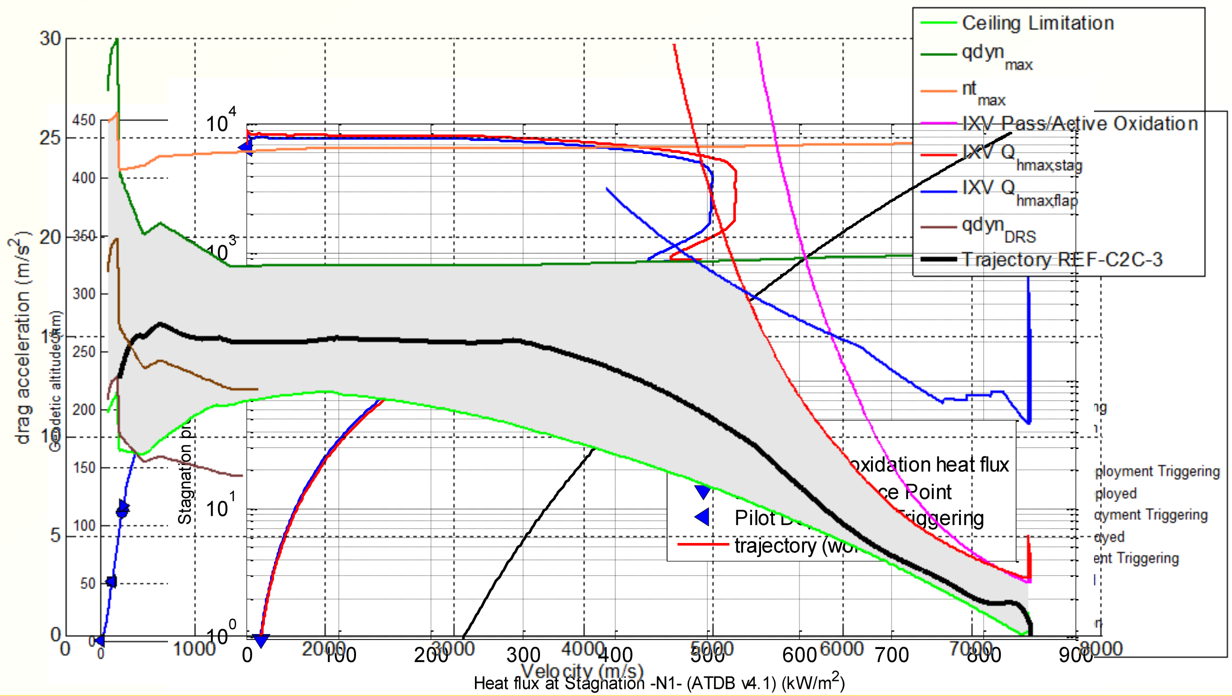
Vehicle Centre of Gravity (CoG) and Trim Line Optimization

- Design solution for Rarefied, Hypersonic and Supersonic flow
- Selection driven by Trim (flaps limits) and Flying Qualities limits
- Robust against uncertainties and AEDB evolutions
- Considers uncertainties, GNC and DRS needs, coupling
- Requirement to AEBB and flap range derived



Major Characteristics

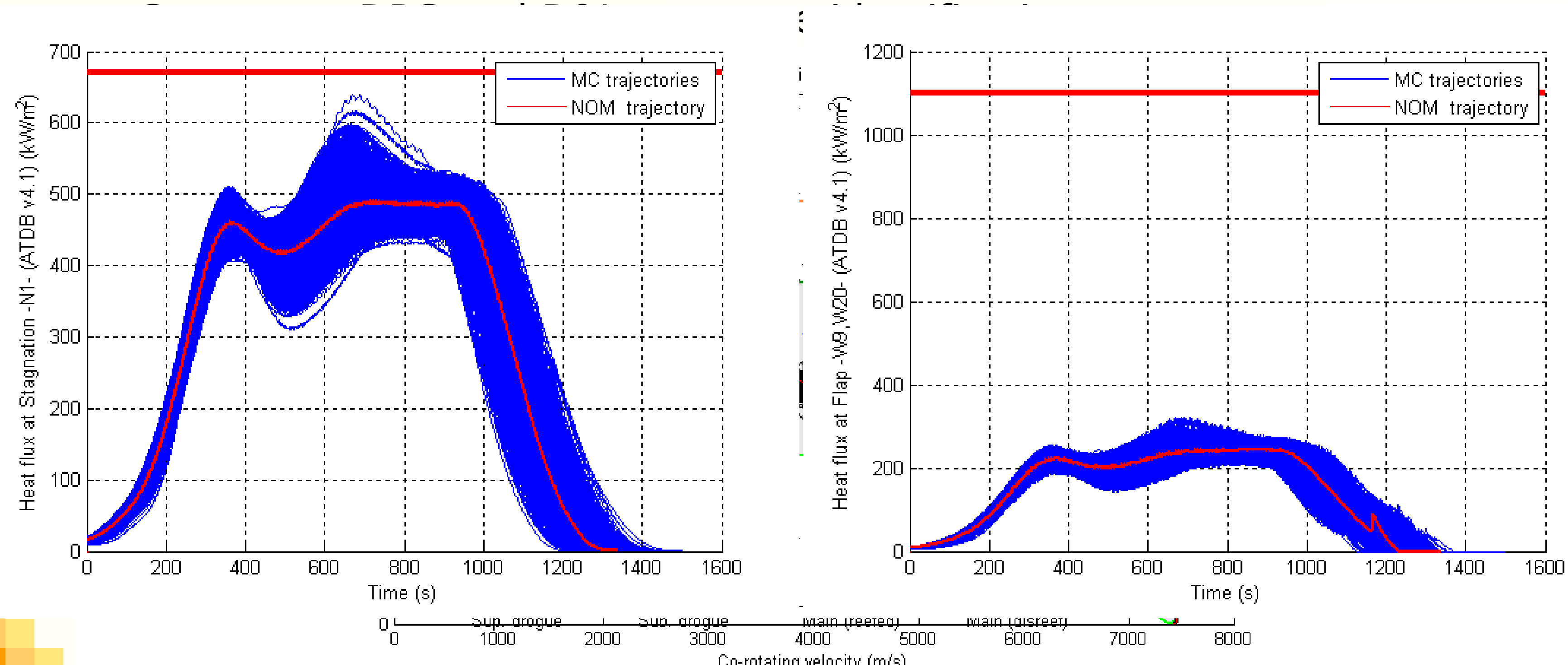
- Single End-2-End Optimisation (SGRA code)
- Accurate ATD predictions (ATDB) ensures automatic ATD verification
- Corridor with margins for GNC
- Safety constraints respected
- Injection Point validated by Launcher Authority
- Compatible with large injection dispersions
- High fidelity environmental models



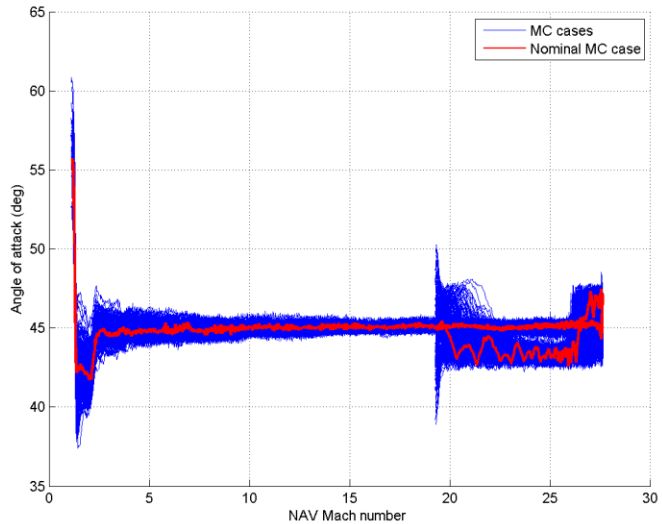
IXV: Mission Performances

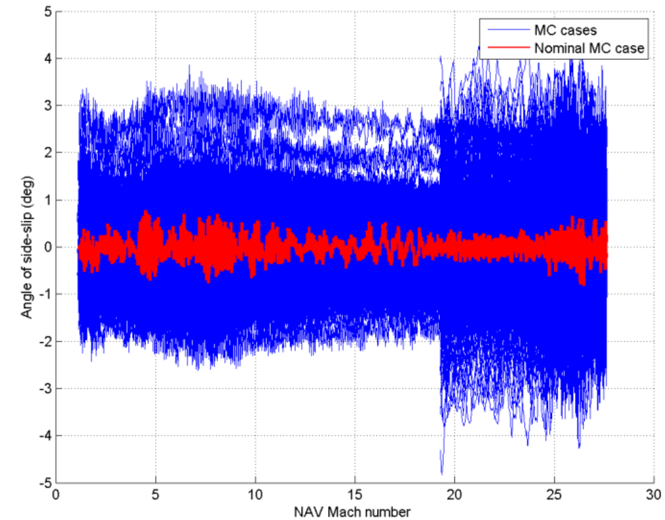
Major Characteristics

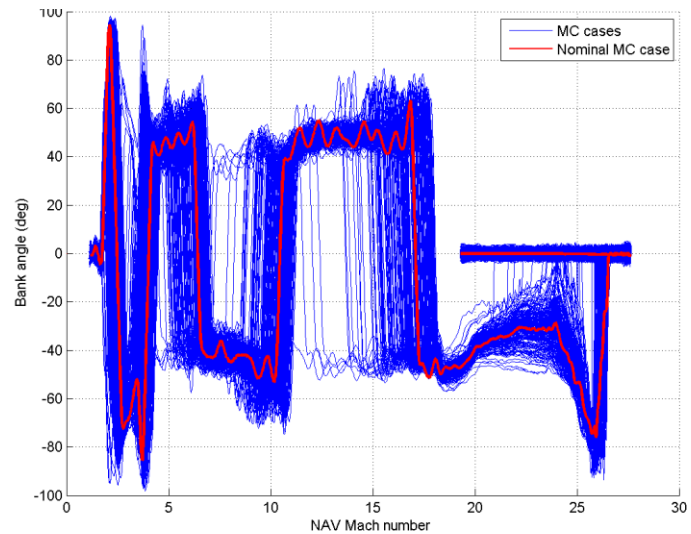
- Orbital – Entry – Descent Phases
- 3DOF and 6DOF GNC Close Loop simulations conducted
- Compliance of all constrains, in particular ATD, with further margins
- Accurate ATD prediction (integrated ATDB Tool)
- Guidance successfully compensates large EIP deviations (> 1400 km)
- Small dispersions at landing



IXV: GNC performances

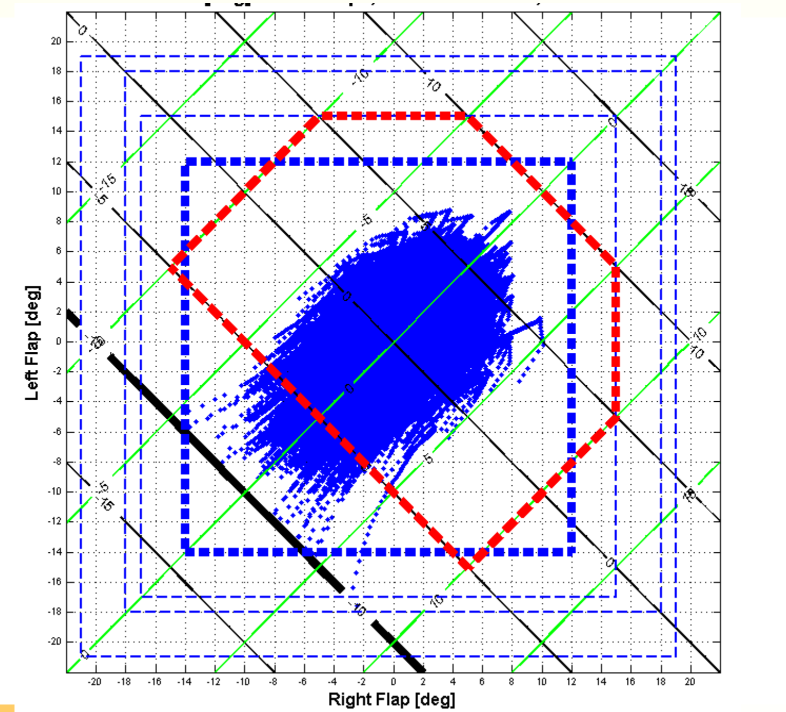


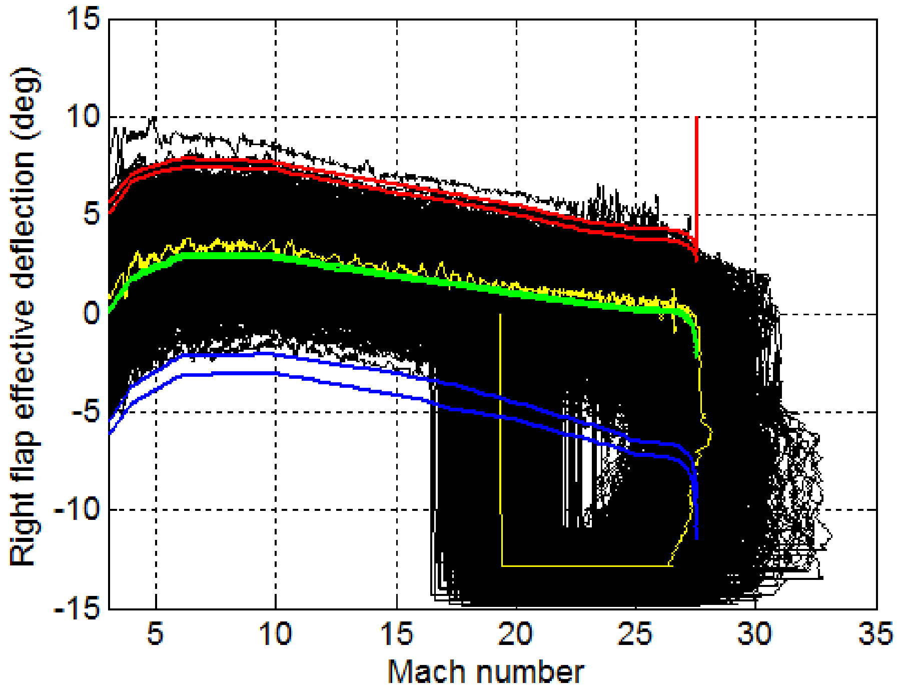




Monte Carlo campaign for verification of performances

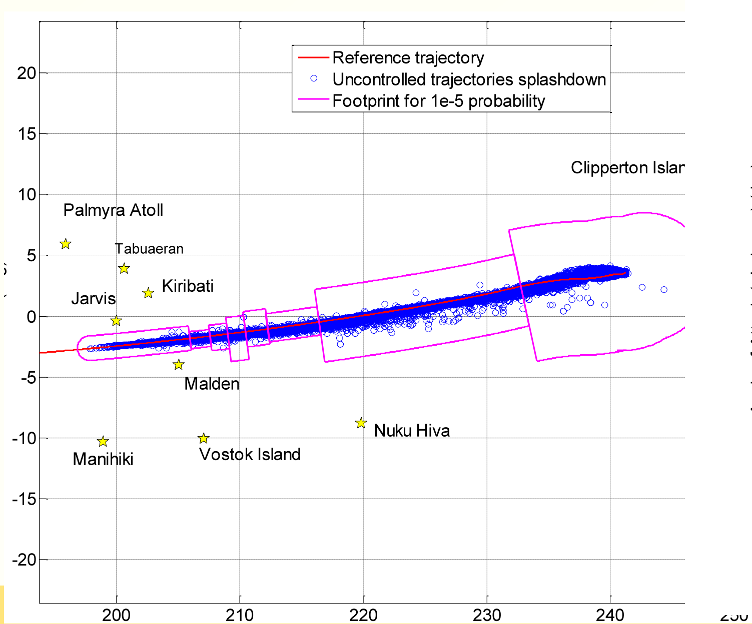
- Uncertainties on Environment, State, MCI, GNC allocation
- Detailed validation of design solution (CoG and Trim) and margins: trim, FQ, couplings
- Cross validation with 6DOF Close Loop GNC Monte Carlo
- Predited AoA corridor performances verified
- Good FQ down to end of the DRS window

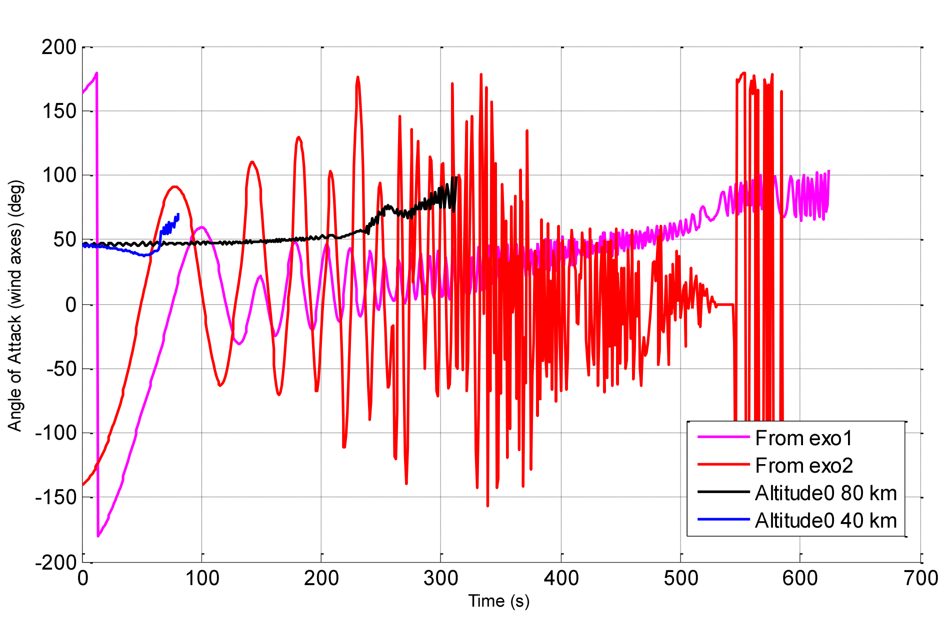




IXV: Safety Footprint

- **Non nominal footprint in case of failure**
- **Failure case:**
  GNC failure at any moment of the flight from AVUM separation to DRS triggering
- **Based on 6DOF Open Loop Monte Carlo simulation**
  – Considers all uncertainties: dispersion in flight conditions, aerodynamics, environment, MCI…
- **No islands (habited or inhabited within the footprint)**



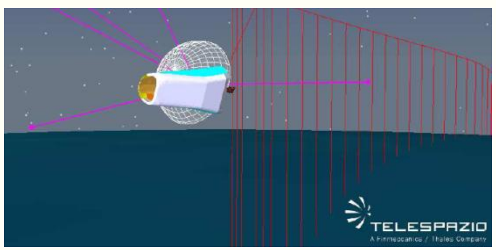


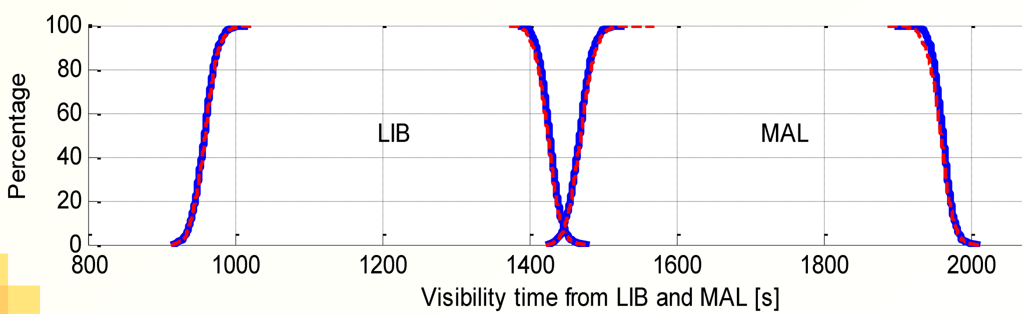
IXV: Visibility

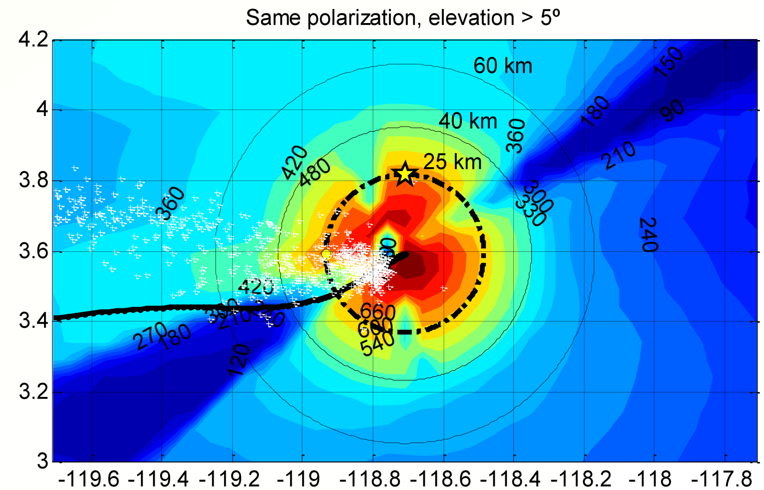
Geometric Connections between IXV and Ground Segment

- Fixed Stations: Performances evaluation and network selection
- Mobile Stations: Performances optimization (best locations)
  - Station on island (around EIP)
  - Station on Recovery Ship (Descent)
- Analyses include antennas masks for two IXV antennas polarizations
- Trajectory and attitude dispersion from Separation to splashdown

Geometric Connections between IXV and GPS







Conclusions

- **A summary of the Mission Analysis and Flight Mechanics of Earth Experimental missions relevant to exploration has been presented**
- **They are key contributors to the exploration in terms of knowledge acquisition, technology readiness and design processes consolidation.**
- **Same Flight Mechanics and Mission Design approach as in Exomars EDM 2016 Mission design have been applied, tailored to the Phase of design**
- **End to End applied not only for mission performance evaluation but during mission design has been proven as a key feature to increase reliability and reduce design loops**
- **Therefore, those Earth mission are not only relevant for the "visible" technological products (h/w) , like TPS or GNC systems, but also for the maturation of the "hidden" ones (paper) like Mission Analysis and Flight Mechanics**

Thank you!

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